

# **The Carbon Products Industry Vision for the Future**



**“We make carbon products to make your products better.”**

*September 1998*

# The Carbon Products Industry Vision for the Future

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## Preface

The carbon products industry is an extremely diverse industry supplying critical materials and components to some of the United States' most essential industries such as aluminum, steel, chemicals, aerospace, electronics, recreation, and environmental protection.

A large portion of the carbon products industry is built on recovering and processing byproducts from other primary operations. This is good from a waste utilization viewpoint, but it means that availability and quality of essential feedstocks for much of the carbon industry are subject to priorities in other business sectors.

The carbon products industry is energy intensive; however, a complete accounting of its energy consumption has never been done. Preliminary estimates in this document are that approximately 0.1 Quad of energy is consumed in just a portion of the annual domestic production. The total annual domestic production and processing of carbon materials and products could well use over 0.25 Quads of energy (1 Quad =  $10^{15}$  BTU).

The U.S. DOE Office of Industrial Technologies (OIT) has recognized carbon products as a cross-cutting technology for its Industries of the Future (IOF) Program and has challenged the industry to develop a long-term vision for the future. The vision development process was initiated on November 19 - 20, 1996 with a workshop at West Virginia University co-sponsored by the OIT, WVU, and the Carbon Products Consortium (CPC). The Carbon Industry Vision Advisory Committee was formed as a follow-up to the Workshop to draft a vision document incorporating workshop conclusions and reflecting broad input from the carbon products industry in general.

This document envisions a carbon products industry in 2020 that is a distinct, cohesive industry whose underlying importance is better recognized and appreciated than it is in 1998. The industry will be more flexible and better able to respond to global opportunities and competition. Aggressive technology development will enable the carbon products industry to meet increasingly stringent environmental regulations and to adapt to changing market demands. For example, the steel mini-mill industry is continually reducing consumption of graphite electrodes per ton of steel produced and the aluminum industry may start replacing carbon anodes with inert anodes. In addition to maintaining its traditional customer base, growth markets such as civil infrastructure, automotive, aerospace, environmental protection, energy storage, and electronics will account for more than 50% of total sales for the carbon products industry in 2020.

In order to achieve the carbon industry vision for the future, technology roadmaps and strategic plans must be developed, within the framework of U.S. and international antitrust laws and regulations. Four areas for future elaboration are proposed in this vision document:

1. **Material Forms and Products:** for example, development of feedstocks optimized for downstream products; R&D partnerships for development of new applications of carbon products.
2. **Manufacturing Technologies:** for example, substantial improvement in asset utilization; innovative continuous processes for multi-stage manufacturing lines.
3. **Energy and Environment:** for example, increase energy efficiency by 25% and reduce emissions of controlled gases by 80%.
4. **Training and Human Resource Issues:** for example, partner with public education and labor organizations for improved workforce development; the industry must assume greater leadership in structuring academic programs.

The stated goal of the IOF program is enhanced industrial productivity through improved energy efficiency and reduced waste in the nation's most energy intensive industries. Investment in carbon technologies as a cross-cut industry in the IOF program can benefit productivity for virtually all of the core IOF industrial sectors, as well as enhance energy efficiency and reduce environmental impacts of many other industry sectors.

The U.S. DOE Office of Industrial Technologies and the Oak Ridge National Laboratory sponsored the November 19 - 20, 1996 workshop, which initiated development of The Carbon Products Industry Vision for the Future. The Carbon Products Consortium has coordinated this and other programs of long-term benefit to the carbon industry. This document could not have been produced without the time, suggestions, and outreach work of the Vision Advisory Committee and participants in the Carbon Products Industry Vision Workshop (listed in Appendix 2). The sponsorship, support, and participation of these individuals and organizations are most gratefully acknowledged.

Washington, D.C.  
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September 11, 1998

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## Looking Ahead to 2013 . . .

*The year is 2013. A new automobile, the 100 MPG "BLACK BEAUTY" is now the consumer rage, appealing to the environmentally conscious as well as to the performance enthusiast. The automobile, once a steel-clad, steel structure, is now a monument to carbon-based engineered materials. The demands for decreased emissions and increased fuel economy have caused the typical vehicle to shed large fractions of its weight. Such enormous weight reductions have been made possible primarily by the extensive use of carbon composite-based materials and lightweight metals utilizing carbon during manufacture. These lightweight materials are found throughout the frame and chassis, in the high efficiency catalytic motor, in lithium batteries and electric motors, body panels, fuel tank and enhanced methane storage materials: in short, in every essential element that makes such a vehicle feasible.*

*SMC body panels with VGCF reinforcement come from the molds with smooth, ready-to-paint surfaces. The submicron carbon fibrils conform easily to the mold surfaces and are electrically conductive, greatly simplifying electrostatic surfacing. Since VGCF polymer composites are chemically inert and not susceptible to ultraviolet degradation, no surface finish is required. In less visible applications, injection-molded VGCF reinforced engine covers, housings, and gear boxes have completely replaced structural metal die castings. The fuel tank is now a CF filament wound pressure vessel filled with activated carbon and carbon fibrils, which enhance containment of natural gas under low pressures. The catalytic engine uses catalysts coated on microspheres of carbon and hollow carbon fullerene tubes. The electronic brains of these power plants and the multitude of sensors, which feed them, have also become much more tolerant of the hot operating conditions. The thermal expansion mismatch failures, which once plagued thermally cycled electronic components, have now been eliminated through the use of CF composite structures. By manipulating fiber orientation, engineers created extraordinary directional thermal conductivity negating the need for active cooling systems and polluting coolants. The electrical conductivity of the carbon-based materials provides EMI shielding enclosures for the electronic enclosures.*

*The lithium/lithium ion battery system utilizes carbon anodes as well as CF polymer cathodes. The new sonic air conditioning, made possible by new CF reinforced plastic radiators, chambers, and insulating carbon foams, provide the utmost in comfort and eliminate ozone unfriendly gases. A built-in communication system provides GPS, cellular phones, fax machines, and an on-board computer, each protected in its ergonomic interior casing by CF EMI shielding.*

*The carbon fiber suspension system was designed by orienting the carbon fibers in the torque arms eliminating numerous components. The carbon-based brake rotors and graphitic pads reduce unsprung weight and provide fade-proof, fail-safe performance. The new carbon fiber reinforced nylon wheels cool the brake system and significantly reduce weight. The new tire tread compounds utilizing spherical and elongated carbon blacks and carbon fibrils with continuous CF belted radials have all but eliminated rolling resistance. The suspension elements, carbon fiber wheels and tires provide electrical conductivity, thereby grounding the vehicle to prevent static-initiated fires during refueling and providing passenger comfort during entry and egress.*

*Catalytic and hybrid electric vehicles now constitute a significant portion of the fleet mix. Gasoline consumption has dropped inversely with the use of natural gas and coal-derived gases. With these domestically produced created fuels, the trade deficit has been largely eliminated and millions of domestic jobs providing fuels, materials, and manufacturing to the new automotive industry of the future, made possible by the engineered use of carbon-based materials.*

– Contributed by Bill Tarasen



## **1.0 The Carbon Products Industry: A Fundamental Global Industry**

The 100 mpg “Black Beauty” automobile described in the above carbon products scenario for 2013 highlights the cross-cutting nature of the carbon industry. Though the scenario sounds futuristic, carbon products are used today in many vehicle systems, and the “Black Beauty” is simply an extension of current carbon technology development. You may not know it, but carbon products are already a critical feature of your automobile and many other basic elements of our economy.

Elemental carbon occurs naturally throughout the world in either its crystalline, more ordered, or amorphous, less ordered form.<sup>1</sup> In its many varying manufactured forms, carbon and graphite can exhibit a wide range of electrical, thermal, and chemical properties that are controlled by the selection of raw materials and thermal processing during manufacture.<sup>1</sup>

As a cross-cutting industry, carbon products have numerous applications across a range of industrial sectors from public works to aerospace. Carbon products are available as end products, such as golf club shafts, activated carbon filters, and as components of rubber compounds. Other carbon products such as carbon anodes are consumed as essential components in the production of end products such as aluminum and steel.

Elemental carbon is transferred on a global scale from one process to the next on its way to final applications. Carbon from oil in the Persian Gulf may pass through several companies in different countries on its path to being processed into a final product.

### **1.1 What is a Carbon Product?**

Essentially any organic material can be thermally transformed to carbon. The carbonization process uses heat to convert organic precursors into a carbon polymer. Some selected precursors can then be transformed into a three-dimensional graphite structure or near-graphite structure.<sup>1</sup> Differences in properties of the final carbon products depend on the raw materials used, on the extent of completion of overall chemical and physical ordering processes, and upon whether the thermal transformation takes place from the vapor, liquid, or solid phase.

Carbon products can be grouped according to the extent of material processing: Raw Material, Carbon Precursors, and Finished Carbon Products. Figure 1 presents an overview of the processing flow from raw material to finished carbon product.

Coal tars and petroleum cokes are the principal raw materials used in the carbon products industry. These materials are by-products of refining and other coal and oil processing operations. In the United States, approximately 1.8 million metric tons of coal tar and 24 million metric tons of petroleum coke are produced each year (the U.S. processes 72% of world-wide production of petroleum coke).<sup>2</sup>

Pitches and cokes, which are derived from coal and petroleum tars or heavy aromatic liquids, are the two main carbon precursor materials for the production of bulk carbon and graphite products, and for the manufacture of carbon blacks. Pitches have a glass-like character and cokes are

infusible solids. Bulk carbon and graphite products, such as electrodes, are produced by first blending calcined coke as a filler and liquid pitch as a binder. This "green" material is then thermally processed through a series of progressively higher temperatures to achieve the final desired properties. Petroleum coke is the largest single precursor material in terms of quantity for manufactured carbon and graphite products. Approximately 10 million tons were consumed worldwide in 1997.<sup>3</sup>

Other precursors include natural graphite, hydrocarbon gases, carbon blacks, anthracite, and synthetic resins. Carbon blacks are nanoscale carbon particulates produced by pyrolysis of feedstocks from the vapor phase with homogeneous nucleation of solid carbon.

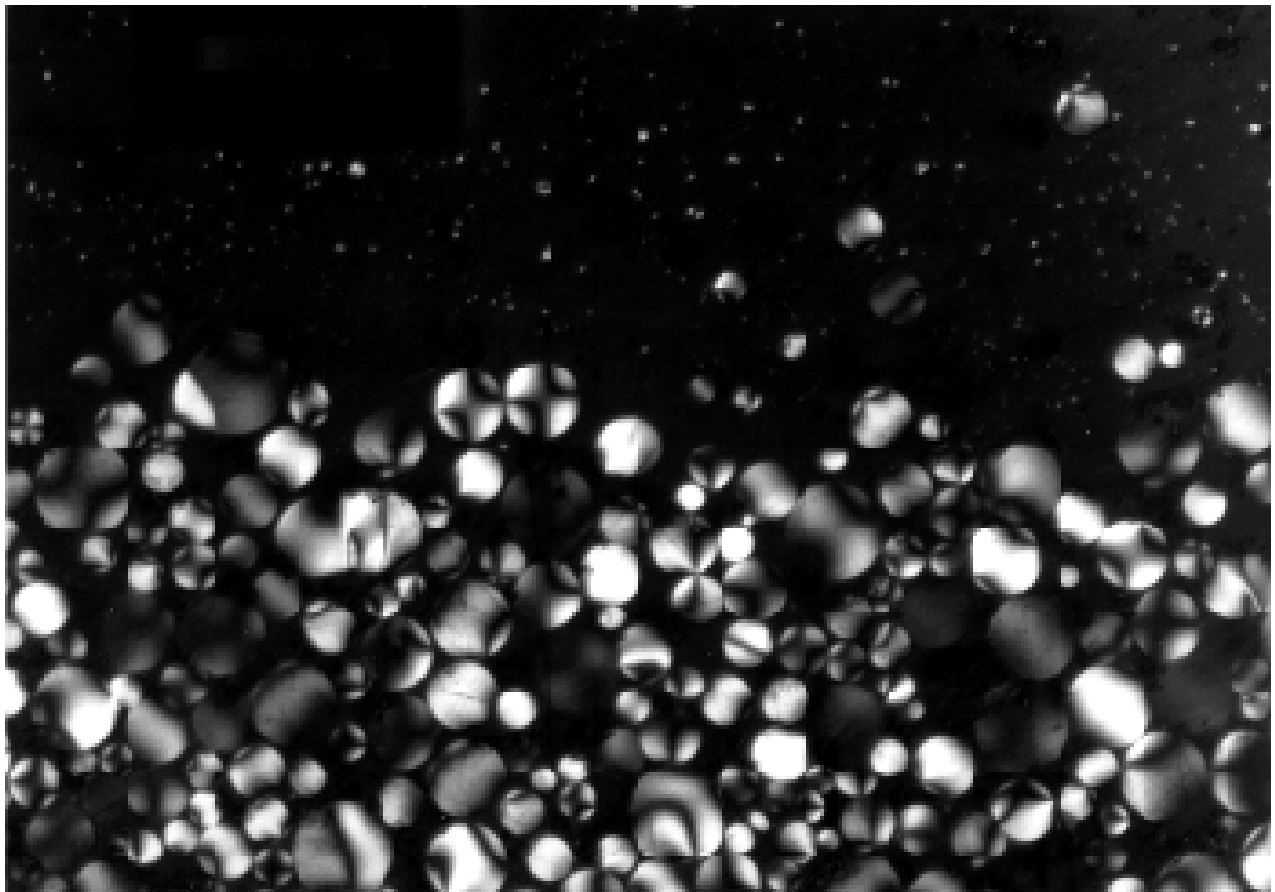
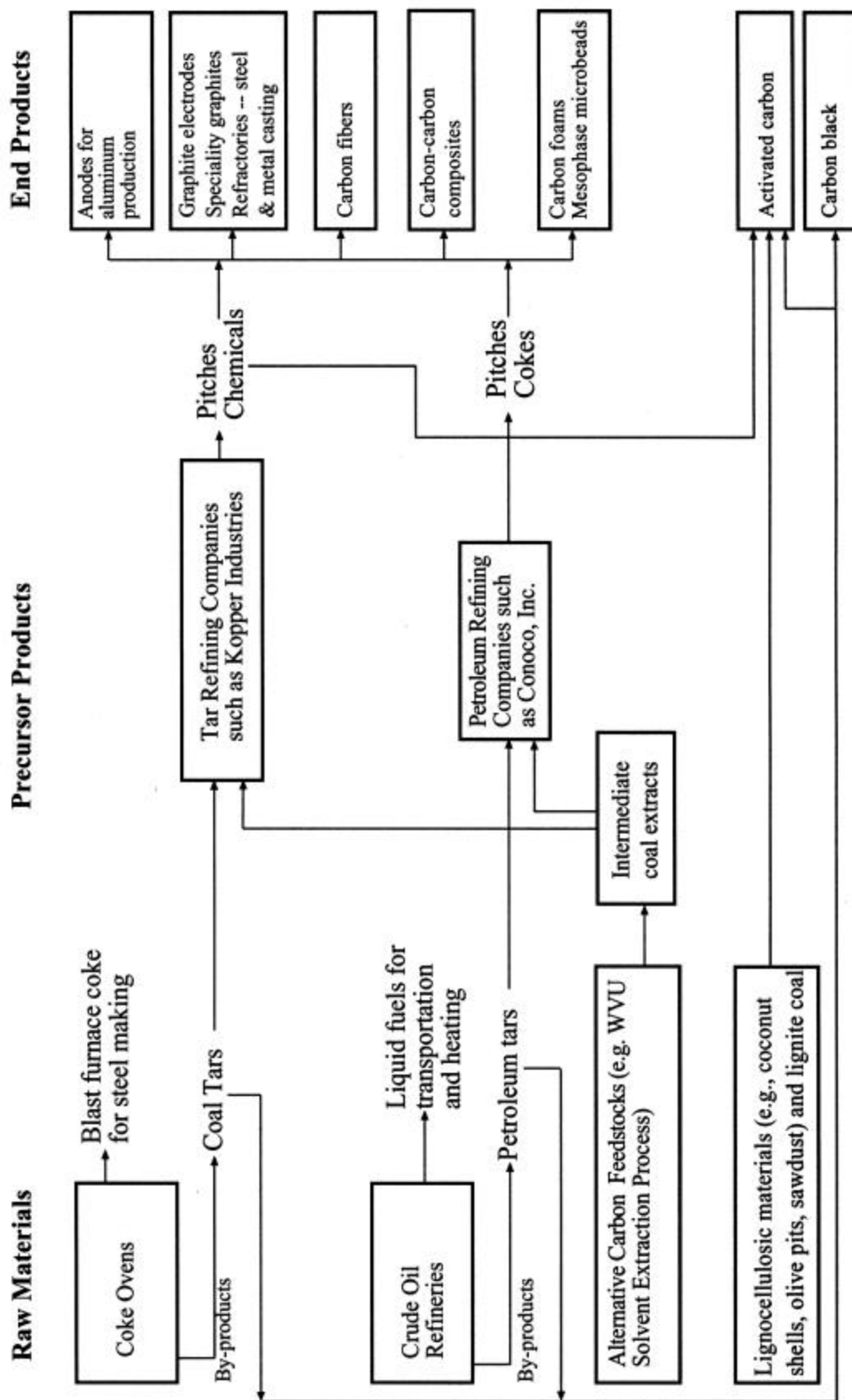


Photo courtesy of Dr. Peter Stansberry, West Virginia University

**Figure 1:** *Spherical carbonaceous liquid crystals growing in coal-derived pitch*

**Figure 1: Material Flows in the Carbon Products Industry**



Carbon precursors can be processed into numerous finished carbon products. Innovative companies continue to find new applications for carbon products. Table 1 lists many of the major applications for carbon products by industry and the requirements that drive the use of carbon materials.

**Table 1: Industry Applications for Carbon Products**

<b>Industry Application</b>	<b>Carbon Products</b>	<b>Requirements for Carbon</b>
<b>Aluminum production</b>	<ul style="list-style-type: none"> <li>• anodes, cathodes and sidewalls in the Hall Heroult primary aluminum cell (1 metric ton of molten aluminum requires about 420 kg of anode carbon).</li> </ul>	<ul style="list-style-type: none"> <li>• resistance to corrosion</li> <li>• resistance to thermal shock</li> <li>• high thermal conductivity</li> <li>• low porosity</li> <li>• high operating strength</li> <li>• electrical conductivity</li> <li>• dimensional stability</li> </ul>
<b>Steel production</b>	<ul style="list-style-type: none"> <li>• electrodes for producing molten steel, iron and other alloys</li> <li>• carbon blocks for hearths and furnace walls</li> <li>• crucibles</li> <li>• pressure casting</li> </ul>	<ul style="list-style-type: none"> <li>• electrical conductivity</li> <li>• resistance to thermal shock</li> <li>• high thermal conductivity</li> <li>• machinable to close tolerances</li> <li>• dimensional stability (low CTE)</li> </ul>
<b>Glass Making</b>	<ul style="list-style-type: none"> <li>• furnace</li> <li>• crucibles</li> <li>• handling mechanisms</li> <li>• heaters</li> </ul>	<ul style="list-style-type: none"> <li>• resistance to thermal shock</li> <li>• machinable to close tolerances</li> <li>• dimensional stability</li> </ul>
<b>Environmental</b>	<ul style="list-style-type: none"> <li>• carbon filters for water and air purification and filtration for industrial, municipal, and automotive applications</li> <li>• mesophase microbeads</li> </ul>	<ul style="list-style-type: none"> <li>• versatile and controllable porosity</li> <li>• tailored chemically reactive surface</li> <li>• large surface area</li> </ul>
<b>Chemical production</b>	<ul style="list-style-type: none"> <li>• reaction vessels</li> <li>• heat exchangers</li> <li>• pumps</li> <li>• pipe fittings and valves</li> <li>• porous graphite filters</li> <li>• anode/cathode electrolytic processing</li> </ul>	<ul style="list-style-type: none"> <li>• resistance to corrosion</li> <li>• high thermal conductivity</li> <li>• tailored chemically reactive surface</li> <li>• low permeability</li> <li>• electrical conductivity</li> </ul>
<b>Aerospace</b>	<ul style="list-style-type: none"> <li>• nose cones</li> <li>• airframe structure</li> <li>• brakes</li> <li>• rocket nozzles</li> </ul>	<ul style="list-style-type: none"> <li>• high strength-to-weight ratio</li> <li>• high thermal conductivity</li> <li>• resistance to thermal shock</li> </ul>

<b>Metals fabrication</b>	<ul style="list-style-type: none"> <li>• high-temperature rollers</li> <li>• dies</li> <li>• tooling</li> <li>• electrodes for electrical discharge machining</li> </ul>	<ul style="list-style-type: none"> <li>• resistance to thermal shock</li> <li>• resistance to corrosion</li> <li>• high thermal conductivity</li> <li>• machinable to close tolerances</li> <li>• mechanical strength</li> </ul>
<b>Nuclear power</b>	<ul style="list-style-type: none"> <li>• nuclear moderators and reflectors</li> <li>• thermal columns</li> <li>• materials for construction</li> <li>• graphite-coated fuel pellets</li> </ul>	<ul style="list-style-type: none"> <li>• low neutron capture cross section</li> <li>• high thermal conductivity</li> <li>• machinable to close tolerances</li> <li>• mechanical strength</li> </ul>
<b>Electronics</b>	<ul style="list-style-type: none"> <li>• electronic components such as capacitors</li> <li>• batteries</li> <li>• heat sinks</li> <li>• electromagnetic shielding</li> <li>• heating elements for semiconductor mfg</li> </ul>	<ul style="list-style-type: none"> <li>• electric conductivity</li> <li>• dimensional stability</li> <li>• resistance to thermal shock</li> <li>• high thermal conductivity</li> <li>• light weight</li> </ul>
<b>Sliding contact mechanical applications</b>	<ul style="list-style-type: none"> <li>• bearings</li> <li>• seals</li> <li>• vanes</li> <li>• bushings</li> <li>• wear rings and brushes</li> </ul>	<ul style="list-style-type: none"> <li>• lubricity</li> <li>• strength</li> <li>• dimensional stability</li> <li>• machinable to close tolerances</li> </ul>
<b>Recreational products</b>	<ul style="list-style-type: none"> <li>• carbon fiber for golf clubs, tennis rackets, skis, bicycles, sailboats</li> </ul>	<ul style="list-style-type: none"> <li>• high strength to weight ratio</li> <li>• fabrication versatility</li> <li>• high stiffness to weight ratio</li> </ul>
<b>Infrastructure</b>	<ul style="list-style-type: none"> <li>• seismic retrofit of beams and columns</li> <li>• life extension of bridges</li> </ul>	<ul style="list-style-type: none"> <li>• high strength to weight ratio</li> <li>• resistance to fatigue and vibration</li> </ul>
<b>Transportation</b>	<ul style="list-style-type: none"> <li>• automotive structures</li> <li>• rotating components</li> </ul>	<ul style="list-style-type: none"> <li>• fabrication flexibility</li> <li>• high stiffness</li> </ul>
<b>Rubber products</b>	<ul style="list-style-type: none"> <li>• carbon black for making tires and rubber; tires alone consume 650,000 tons/yr of carbon black</li> </ul>	<ul style="list-style-type: none"> <li>• structured particulates of controlled morphology</li> <li>• readily wet by rubbers</li> <li>• thermally stable, mechanically robust</li> </ul>

## **1.2 Markets/Applications: Raw material to end product**

Demand for carbon products is projected to increase as a result of new applications for carbon products and steady growth in existing applications. For current applications, Table 2 lists approximate price, volume and market projections for carbon feedstocks. Table 3 lists similar information for major current carbon products.

Market growth for carbon products is strongest for the value-added segment of the carbon products industry. Companies are finding additional applications for the relatively high-value carbon products (greater than \$4/lb) and are developing new carbon products that sell for tens to hundreds of dollars per pound. These high-value products take advantage of unique properties of carbon materials to offer customers superior performance on existing or new applications.

New and emerging markets for carbon products include consumer electronics such as heat sinks for high density computer chips, activated carbon filters and beds to clean various air emissions and aqueous streams, carbon materials for batteries, fuel cells, and for other energy storage devices such as flywheels, surface transportation applications such as lightweight chassis components for highly efficient vehicles, and civil infrastructure applications for repair and retrofit of buildings and bridges.

**Table 2: Intermediate Carbon Products Summary**

<b>Product</b>	<b>Feedstock<sup>1</sup></b>	<b>Domestic Annual Sales<sup>2</sup></b>	<b>Worldwide Annual Sales<sup>2</sup></b>	<b>Status and Projections</b>
<b>Binder Pitch</b>	CT from coke ovens	900,000 T \$175 M	1,500,000 T \$525 M	Declining supply of CT due to changes in steel processing.
<b>Impregnating Pitch</b>	PT (USA) CT (elsewhere)	200,000 T \$50 M	380,000 T \$95 M	Adequate for demand
<b>Mesophase Pitch</b>	PP (USA) CTP (Japan, Korea) Naphthalene	No domestic sales of mesophase petroleum pitch	3,700 T	No CT mesophase pitch produced in USA. Petroleum mesophase used internally
<b>Anode Coke</b>	PT (USA) CT, PT (Japan)	2,000,000 T \$400 M	8,000,000 T \$1,600 M	Declining quality of PT due to high levels of sulfur and vanadium in imported crude oil. 4% annual increase in demand will result from growth in aluminum production.
<b>Needle Coke</b>	PT in USA PT & CT in Japan	400,000 T \$160 M	1,300,000 T \$552.5 M	Mature business but estimated slow growth of about 1% - 2% annually
<b>Carbon Black</b>	90% PT 10% CT	1,500,000 T \$450 M	7,000,000 T \$1,800 M	Somewhat cyclical with vehicle part and vehicle production, net world-wide growth projected at 2% to 3% annually.

- Notes: 1) PT = Petroleum tar ; CT = Coal tar; PP = Petroleum pitch; CTP = Coal tar pitch  
2) T = Metric tons, M = Millions of dollars  
3) Source: Carbon Products for Industrial Cross-Cut Technologies, a paper presented by Caulton L. Irwin at the DOE 2nd Industrial Energy Efficiency Symposium and Expo, Feb. 24-26, 1997. Production and sales data updated to 1998 where possible.

**Table 3: Finished Carbon Products Summary**

Product	Feedstock <sup>1</sup>	Domestic Annual Sales <sup>2</sup>	Worldwide Annual Sales <sup>2</sup>	Status and Projections
<b>Carbon Anodes</b>	Calcined coke, Binder pitch	1,600,000 T \$500 M	7,500,000 T \$2,340 M	3% to 4% annual growth in world-wide aluminum production will support sustained growth.
<b>Graphite Electrodes</b>	Needle coke, Binder pitch, Impregnating pitch	400,000 T \$1,000 M	1,100,000 T \$2,750 M	Slow growth in demand due to improved efficiencies but growing emphasis by EAF.
<b>Specialty Graphite</b>	Cokes, Binder pitch, Impregnating pitch	30,000 T \$200 M	200,000 T \$1 billion	New applications such as fine grain specialty graphites will expand sales.
<b>Activated Carbon</b>	Various organic precursors, including coal and cellulose material	193,000 T \$415 M	551,000 T \$1,181 M	Excellent growth potential for air and water purification applications resulting from tighter environmental regulation and sustainable development.
<b>Low-Cost Carbon Fibers</b>	85% PAN 15% CTP (Japan)	4,000 T \$90 M	5,000 T \$110 M	High growth levels projected as large-volume markets such as vehicles and construction use fibers at about \$8/lb.
<b>High-Performance Carbon Fiber</b>	90% PAN 10% CTP (Japan)	3,750 T \$260 M	8,000 T \$560 M	Cyclic aerospace demand drives market. Moderate growth in demand from recreational products.
<b>Carbon-Carbon Composites</b>	Carbon fibers and matrix pitch	600 T \$90 M Brakes \$50 M Other	1,200 T \$280 M	Cyclic aerospace demand drives market.

See notes for Table 2.



Photo courtesy of UCAR Carbon Company, Inc.

**Figure 3:** *Specialty graphites*

### **1.3 Carbon Products Industry is a Major Energy User**

In general, making carbon products requires large amounts of heat energy since most carbon products are processed at high temperatures. Some carbon products go through a number of process steps involving elevated temperatures as high as 3000° C. The cost of this energy is often a significant portion of the total cost for a carbon product.

For example, approximately 120 million BTUs per ton are consumed annually in the production of graphite electrodes for use in electric arc furnaces. Assuming 400,000 metric tons per year domestic production, approximately 48 trillion BTUs are consumed annually in production of graphite electrodes. Similarly, the annual U.S. production of approximately 30,000 metric tons of specialty graphites, consumes about 8 trillion BTUs of energy through baking and graphitizing operations.

In addition, 3.5 million BTUs are required to produce one ton of calcined coke, a carbon product used to make anodes for aluminum production. Approximately 2 million tons of anode coke are produced each year in the U.S., therefore consuming roughly 7 trillion BTUs each year.

As another example, energy use accounts for about 10% of the per pound cost for carbon-carbon materials, which are used in aircraft brakes, rocket nose cones, and other high temperature applications. About 1.7 million BTUs are required to produce one pound of carbon-carbon material. Approximately 600 tons of carbon-carbon are produced each year in the U.S., requiring about 2 trillion BTUs per year. Nearly all of this energy for making carbon-carbon materials comes from natural gas.

The carbon products industry is a major energy consumer in the U.S. As estimated above, the domestic production of graphite electrodes, calcined coke, specialty graphites, and carbon composites, requires approximately 65 trillion BTUs per year (not including energy consumed in baking anodes for aluminum smelting). When energy requirements for producing other carbon products are included, energy consumption in the carbon products industry could reach well over 100 trillion BTUs per year. As such, the industry is very sensitive to energy pricing and energy supply. The carbon industry works closely with utilities to reduce its energy costs as much as possible. Moreover, the industry continually works to improve product processing and to increase energy efficiency.

### **1.4 Structure of the Carbon Products Industry**

There are relatively few producers in the U.S. carbon products industry. High capital equipment and facility costs tend to limit the number of companies that can produce raw materials and carbon precursors. Greater diversity can be found at the finished products end where a greater number of smaller manufacturers and fabricators supply particular carbon products to different markets.

*Raw materials* — Coal tars and petroleum tars, the raw materials for most carbon products, are sold as by-products of other operations including refining of crude oil for fuels and the making of blast furnace coke for steel production. The raw material supply for the carbon industry is therefore subject to events and conditions in other primary markets. This situation is undesirable and companies and organizations dependent on quality materials support research on alternate



sources of supply (e.g., solvent extraction processes to produce aromatic polymer precursors directly from coal, coal tar and petroleum tar combinations, and anthracite and epoxy resin developed in Norway).

*Carbon black* — The carbon black industry experienced significant consolidation in the 1980s as a result of the switch to radial tires and the consequent increase in miles driven per tire. Today there are six major suppliers to the U.S. market. Of these, three are the major worldwide suppliers as well. These three suppliers account for nearly 60% of world production. There are also a number of local country suppliers because carbon black is relatively inexpensive and very bulky, hence shipping distance is limited. Economies of scale in this industry lie in commercial relationships, technology development, and technology optimization, and not so much in the size of scale of an individual plant which is logistically limited.

*Carbon precursors* — Producers of carbon precursors process coal and petroleum tars into a range of chemical products, including pitches, cokes and monomers for making engineered plastics.<sup>5</sup> These companies are generally large, multinational chemical concerns making materials on a commodity basis. In many cases these companies have corporate ties or other strong relationships with raw materials suppliers (e.g., Conoco, Inc. operates refining operations that produce raw tars and operates coking and calcining facilities that make carbon product precursors). Suppliers of carbon precursors tend to invest more to improve production efficiencies.

*Finished products* — Companies making finished carbon products are more closely aligned with their customers. Operations are organized around particular products or services with investments directed more toward processing technologies and new product development. These companies are closest to the end users of carbon products and are often more visible to suppliers and customers than to the general public.

Some consolidation occurred within the carbon products industry in the late 1980's and early 1990's. Some companies merged with their competitors or suppliers, purchased idled capacities or even exited the business entirely. This consolidation continues today, to a lesser extent, in more mature market segments.

During this period U.S. companies also shifted some of their operations offshore to control operating costs and follow the shift in operations of certain heavy industry, such as steel making and chemical production, which are principal markets for many of the suppliers for raw material and carbon precursors. Activated carbon was an exception; production of activated carbon increased in the U.S. during the last ten years and producers have not yet shifted operations off shore.



See photo credits, page 24

**Figure 4:** *Carbon composite recreational products*

## 2.0 Competitive Challenges and Opportunities

The carbon products industry responds to many trends and opportunities in both the domestic and global economies. With distributed end markets, carbon products are sensitive to a wide range of factors that influence business planning.

Demand for carbon products and the structure of the industry are some of the more significant drivers for the future of the carbon products industry. Projected increases in global demand for carbon products result from continued growth in current markets and development of new markets for carbon products (e.g., automotive, computers, and environmental). Growth will also result from increased global demand for carbon-consuming products such as aluminum and steel. Additional growth for carbon products will result from environmental pressures to reduce greenhouse emissions and improve water quality, and to reduce evaporative emissions from automotive engines.<sup>6</sup>

Two conflicting trends will affect the structure of the carbon products industry. In more mature markets, companies are consolidating and merging to maximize return on capital. At the same time, new companies are forming and spinning off to follow new markets for carbon products in areas such as reinforcing buildings and bridges. Globalization will also influence the industry structure by driving manufacturing operations to developing countries.

Trends and challenges for the carbon products industry can be grouped into the following categories:<sup>7</sup>

## **2.1 Demand for Carbon Products**

- Increasing globalization of the economy will: generate new markets; move manufacturing off-shore; tighten supply of raw materials; increase demand for carbon-consuming products such as aluminum, and activated carbon; cause increased pressure to hold down costs.
- Increase in imported feedstocks will result in: lower quality precursor materials; higher costs for raw materials; demand for alternate material forms.
- Aggressive environmental policies will: generate demand in end use areas such as efficient transportation systems that use carbon products, water purifiers, and more efficient energy-intensive processes such as electric-arc furnaces.
- Increased costs for energy have the potential to strangle the economy and limit growth.
- World-wide pitch and coke requirements for the aluminum industry will more than double by 2020.

## **2.2 Technology Development and Applications**

- Increased demand for low-cost processing technologies will result from pressure on prices for end-use products such as aluminum and carbon fiber composite products. In today's market, the automotive industry would require carbon fibers in the range of \$3 - \$5 per pound for large-scale implementation.<sup>8</sup>
- Increased emphasis on coal as a source of precursor material for carbon products.
- Increased emphasis on co-processing technologies for coal, e.g., co-producing carbon products, fuels and electrical power.
- Processing technology will be needed to adjust for declining raw material quality and development of high-quality alternative raw materials.
- Modification of the surface chemical properties of carbon blacks to improve compatibility and/or functionality with the media in which they are used.
- Pre-incorporation of carbon black into rubber media at a stage when both the carbon black and the rubber are finely divided, then conversion of this mixture to an efficient shipping form.
- Technologies for recycling carbon products will be needed as well as mechanisms to reduce the negative environmental impacts of producing carbon products.

- Competing products will be a threat to displace carbon products in some applications (e.g., silica for tires as replacement for carbon black, technologies for color removal versus activated carbon, aluminum and metals versus carbon composites, non-carbon inert anodes for aluminum reduction cells).

### **2.3 Human Resources**

- Aging/retiring workforce will present major challenges to industry to transfer knowledge base.
- Globalization and process improvements will require workforce to be more flexible.
- Information technology explosion and ready access to information will change the way people solve problems. Workforce must be better prepared to use information tools effectively in the workplace.
- Cost containment will force value added components down to every level. Workforce will be more hands-on or involved in the product stream. Workers will pick up more and more responsibilities and duties.
- Severe shortage of carbon scientists worldwide is predicted.

### **2.4 Markets**

- Customer base will become more diverse and have specialized needs requiring new, flexible technologies with shorter production runs and smaller production batches. Result is less dependence on old larger markets.
- More sophisticated customers will demand more value-added products.
- Increased demand for high-strength, low-weight materials could result in growth in the carbon products industry — for carbon products themselves and for products such as aluminum that consume carbon products in their manufacture.
- Foreign competition will increase dramatically requiring U.S. companies to be more competitive or to learn to partner with foreign companies.

### **2.5 Industry Structure**

- Improved manufacturing processes will open new markets for carbon products and support growth of new companies. As costs for carbon products come down, more such products will enter into commodity markets.
- In established markets, global competition and cost pressure is likely to force continued industry consolidation and result in a few strong world players.
- New applications in high-tech industries will increase demand for new, innovative carbon products.



See photo credits, page 24

**Figure 5:** *Heavy vehicles, electric and hybrid electric vehicles, and Indy racecars all use carbon composite materials*

### 3.0 Scenario for the Future

The carbon products industry developed its vision statement based on results from an industry vision workshop sponsored by the U.S. DOE Office of Industrial Technologies in November 1996. The vision statement combines key principles which the industry seeks to preserve in its growth and transition. The vision statement also serves as a guide to future cooperation with industry, customers and stakeholders.

## Carbon Industry Vision Statement

*In the year 2020, the U.S. carbon products industry shall be a cohesive, distinct and essential industry sector that researches, develops, manufactures, captively consumes, and sells carbon-based products. This industry shall be flexible and globally competitive with raw material, intermediate and finished products passing smoothly between countries and across geographic boundaries. The carbon products industry shall be profitable with reinvestment quality economics, where business processes and core competencies are reviewed to ensure that value-added and growth markets/applications are vigorously pursued and developed.*

*A diverse carbon products workforce shall be a flexible resource engaged in continuous learning. Safety shall be the way the industry works. Customer needs and product quality shall always be a top priority. The carbon products industry shall also be globally environmentally responsible, both in its operations and in its products that purify the environment.*

*The carbon products industry shall maintain its strong applied research focus. The industry shall continue to push the technology envelope and shall establish a strong cooperative applied research effort (industry/government/university) to improve energy efficiency, process productivity, and the quality of carbon products. The industry shall develop new, secure sources of high-quality carbon feedstocks that can be used by a number of different carbon manufacturing processes.*

Greater cooperation within the industry and increased industry visibility are fundamental components of this carbon industry vision. Though carbon products are essential to a wide range of basic processes and commodity products in the global economy (e.g., energy production, production of metals, chemical formulations and reactions), today the carbon products industry is not widely recognized or understood. By serving various customers and markets, the carbon industry today is also highly fragmented. To have a collective industry vision and accomplish common objectives, the carbon products industry must get organized.

Globalization is another fundamental element of the carbon industry vision. Pressure to contain and lower costs will increase substantially by 2020 as developing countries continue to bring on line their own industries. Demand for goods and processes will flow quickly to sources with the lowest costs.

Technology advancement, however, will moderate any long-term shifts in production operations. Like a giant mixing spoon, technology advancement in the form of process and efficiency improvements, new products, and new applications will tend to reorder the cost parameters within

the industry. Work and activities will flow back and forth as each improvement outperforms the other or changes the current cost paradigms. The pace of technology advancement shows no signs of slowing, so by 2020 companies must be highly flexible to adjust to new modes of operations, shift operations and activities, and respond to new opportunities. Investments in employee resources and investments in technology will be essential to maintain profitability and stability within the industry.

The carbon industry workforce will assume greater responsibilities by 2020. Routine operations will be automated or outsourced. Increased process flexibility will enable closer relations with customers and require workers to tailor their products to individual customer needs. More comprehensive training will be necessary to provide workers with broader skills and product knowledge. To maintain domestic technological competitiveness, academia must produce highly trained and creative carbon scientists.

In the coming dynamic environment, companies will need to invest in technology development to stay competitive. Properly directed consortia will become an increasingly important mechanism to more effectively utilize scarce research dollars. Research teams from industry, government and academia will provide revolutionary technology advancements. Incremental or applied research will be conducted by vertically integrated teams that include the customer (Market Driven Management). By 2020, time to market/practice for new products and processes will be so short that customers must assume strong roles in development.

Sustainable development will drive environmental policies around the world. These policies will support large markets for carbon products (e.g., activated carbon water filters) and will influence production methods and operating procedures. The carbon products industry will be a leader in practicing sustainable development because of the high capital equipment investments characteristic of the industry. Plants and facilities will continue to be the focus of environmental regulation and pollution avoidance.

## **4.0 Carbon Products Industry Core Competencies**

Excellence in four core competencies will be critical to the success of the carbon products industry in 2020. Industry and government investment in areas such as material forms, processing technology, recycling and energy efficiency, and human resources will position the industry for the future.

### **4.1 New and Higher Quality Material Forms**

Carbon products are derived from raw materials that are declining in quality and increasing in cost. For example, available petroleum supplies are increasingly rich in sulfur, vanadium, and nickel.<sup>2</sup> These impurities adversely affect carbon blacks and processing of metals such as aluminum. Customers are already pressing the carbon industry for solutions to this problem. Investments will be needed to remove the sulfur and other impurities and/or to develop alternative raw materials (e.g., synthetic feedstocks or coal-based pitches that have lower sulfur and metals content than petroleum pitches).



As by-products of other processes, raw materials for cokes and pitches in the carbon industry are susceptible to events in other markets. For example, changes and improvements in steel production and environmental regulations on coke processing are forcing coking plants to close or shut down, resulting in a 3% - 4% per year drop in domestic coke production.<sup>2</sup> The rising cost of petroleum is also a long-term issue. Though prices have been relatively stable over the last seven years, petroleum price volatility is a significant business risk for the carbon products industry. Investments will be needed to develop alternative raw material supplies.



See photo credits, page 24

**Figure 6:** *Aerospace applications of carbon composites – Stealth Bomber Graphite wing molds produced by UCAR Composites Inc.*

New material forms are also needed to respond to market opportunities. Novel material forms such as carbon foams and thick bundled carbon fiber may open new markets for carbon products. As markets for carbon products expand, the volume-price relationship feeds upon itself so that new applications become economically feasible and require higher volume production which supports further price reductions. For example, tremendous demand is forecast in surface transportation and civil infrastructure markets<sup>9</sup> for commodity-priced carbon fibers (approximately \$5 - \$8 per pound relative to 1998 markets). Some large-scale infrastructure applications under consideration today require an entire year's production capacity of a medium-scale carbon fiber plant. Carbon fiber volumes required for automotive and heavy vehicle applications are also very large in terms of current carbon fiber production capacity. Although high end and cyclical markets such as aerospace are intriguing, low cost carbon fibers with reasonable strength and modulus could present a major opportunity for future composite applications.

Continued industry growth depends on the identification and pursuit of new market opportunities. For example, the use of carbon materials as anodes for lithium batteries has created a new and rapidly growing market for various forms of carbon and graphite.

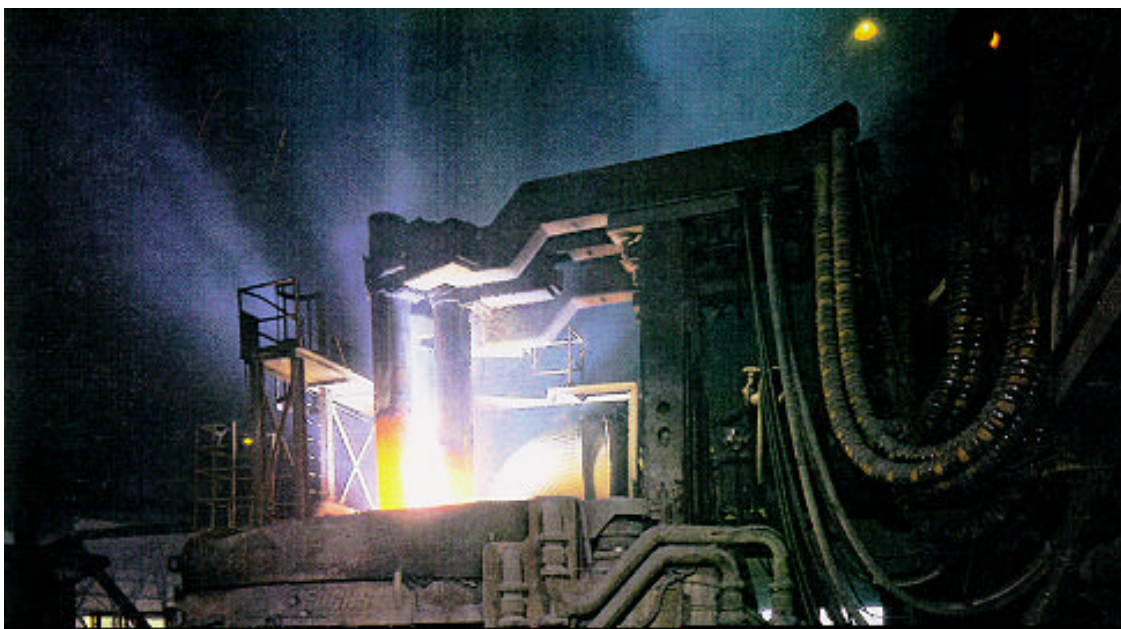


## **4.2 Improved Manufacturing Technologies**

Advancements in processing technologies will be critical to preserving carbon industry employment levels in the United States. Production operations will move overseas unless improvements in processing technologies offset lower operating costs available in developing countries.

Improved energy efficiency for manufacturing and processing will be critical to the competitiveness of U.S. companies. Production of carbon products is energy-intensive. Energy can account for up to one-third of the cost for producing certain graphite products. Graphitizing carbon materials requires temperatures approaching 3,000° C. Precursor steps such as calcining and baking require exposure to up to 2,000° C.<sup>1</sup> Electric and gas-fired furnaces produce the necessary heat and consume significant quantities of energy. Industry is introducing more efficient furnaces and heating and cooling technologies in order to reduce energy costs.

Process improvements under consideration with potentially large payoff include continuous processing of carbon products. Moving immediately from one heating stage to the next in continuous processing would eliminate cool cycles, saving significant amounts of energy currently expended to ramp temperatures back up to the 1,000+° C processing temperatures.



See photo credits, page 24

**Figure 7:** *Electric Arc furnace*

Greater capture and reuse of heat would also improve energy efficiency. Similarly, more efficient use of low-BTU gas created in the manufacture of carbon black presents another opportunity for energy savings. Low-temperature processing of carbon materials is a greater long-range technology advancement with potential to improve energy efficiency significantly.

### **4.3 Sustainable Development**

Sustainable development will be accepted industry practice by 2020. If carbon products are not consumed in their end-use application (e.g., furnace applications), larger amounts of residual carbon materials must be recyclable. For example, recyclability is a major goal for the automotive industry. Today the auto makers claim that over 90% of each vehicle can be recycled. Carbon products must contribute towards the automakers' objectives to reach 100% recyclability.

Recycling vehicle tires is a critical challenge for suppliers of carbon black. Recycling efforts such as using shredded tires in highway paving and pyrolysis of rubber for petrochemical feedstocks are not proving economically viable for reducing the accumulation of used tires. Innovative research is needed to address this global recycling challenge.

Successful recycling efforts include making new anodes by aluminum producers from partially consumed carbon anodes that are recovered and recycled. Also, used and scrap bulk graphite products are converted to powders and sold for various applications by graphite producers and by independent distributors.

On the other hand, sustainable development practices will open new markets for carbon products. For example, demand for activated carbon used in water filtration will increase as more regions of the world focus on water quality. Clean air initiatives will also generate greater demand for carbon-based filtration systems. For example, to respond to U.S. Environment Protection Agency regulations requiring on-board vapor recovery systems on all vehicles, activated carbon filters will be installed on every vehicle.

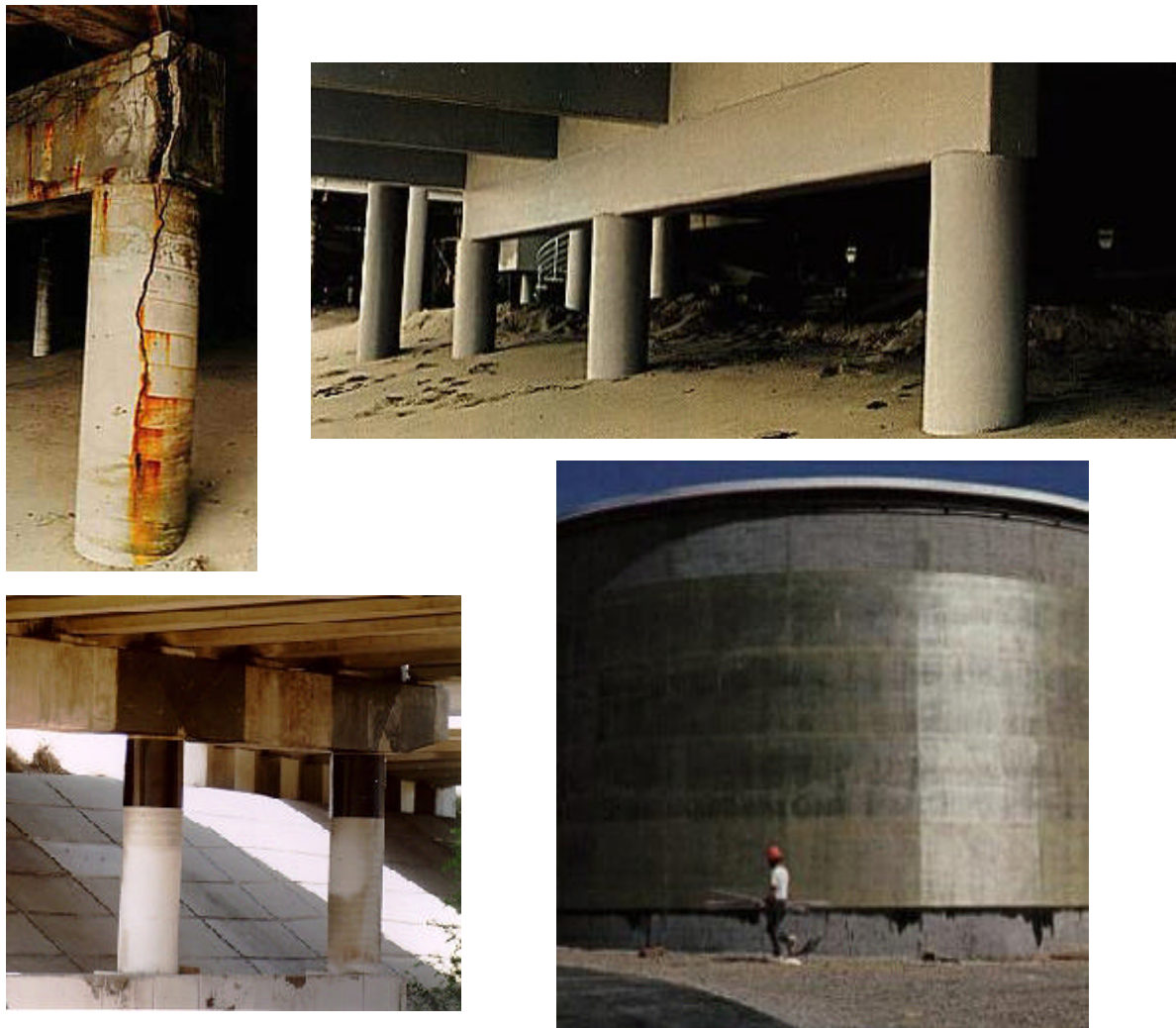
Industry investments in sustainable development can be good for the environment and for the industry balance sheet. For example, use of activated carbon filter systems to recover solvents used in making video tape enable reuse of the solvents in the video tape production process, thus reducing the amount of solvent ultimately released into the environment. The vapor-recovery systems mentioned above capture evaporated gasoline and return it to vehicle engines for combustion, thereby increasing automobile gas mileage.<sup>6</sup>

### **4.4 Training and Human Resources**

Advancements in core competencies discussed above will not take hold in the carbon products industry without investments in human resources. Training requirements actually increase as companies automate processes. Remaining workers often cover more aspects of production and assume greater responsibility for running automated processes. Training requirements also increase with the introduction of new products and advancements in manufacturing technologies. Companies already see increased training and education requirements with the information age expanding to the factory floor. Workers require broader skills to manage optimized processes and to make decisions faster based on more detailed information often available in real time. The need for more training and education will force closer relationships between companies, community colleges and universities. Companies will no longer be able to simply hire people on demand. Personnel will become more of a long-lead time item. Companies will either set up their own training programs or they will work with universities and other organizations to teach the skills needed in the industry.

The number of graduate degree programs in carbon products is currently declining in the U.S. The U.S. carbon industry is seeing a deficiency in the number of carbon scientists available for R&D. Universities in the rest of the world, however, continue to produce carbon scientists and to advance the basic understanding of carbon technologies, which is essential to industry competitiveness. Industry and academia will need to work together to address this problem.

Training requirements and investments in new technologies will result in more industry/academia/government partnerships or consortia. These partnerships will continue to be an important means of meeting future needs of the carbon industry workforce at all levels.



See photo credits, page 24

**Figure 8:** *Infrastructure restoration using carbon composite materials*

## 5.0 Strategic Recommendations

In order to implement this carbon industry vision and act effectively on any strategic recommendations, the carbon industry must be better organized as a collective body. This fundamental recommendation is implied by the development of the carbon industry vision. However, in order to improve efficiency, quality and technology, work needs to be done to coordinate the various components of the carbon industry (e.g., raw materials, suppliers of carbon precursors, chemical interests, fiber producers, producers of graphite electrodes, suppliers of activated carbon, etc.) and to give the industry a greater common identity. A broad-based carbon products trade association may emerge as a mechanism to highlight common industry issues. Such an association would include the complete product/supply chain of the carbon products industry—ranging from feedstocks and precursors through intermediate materials and final consumer products. This potential trade association could focus on efficiency improvements, cost reductions, and productivity enhancements within the industry.

Other strategic recommendations can be grouped according to the core competencies for the future of the industry: material forms, manufacturing technologies, sustainable development, and human resources. The recommendations in the following sections form the basic outline for a technology roadmap. Therefore, these recommendations may change. The roadmap will be developed by industry as a separate initiative and will include specific performance targets and technical recommendations.

### **5.1 New and Higher Quality Materials and Products**

- Develop new forms of carbon feedstock as alternatives to petroleum feedstock (e.g., coal-based precursors<sup>5,10,11</sup> with high average molecular weights and other novel or non-traditional feedstock). The industry must move toward direct feedstock sources optimized for downstream carbon products rather than depend exclusively on feedstocks derived indirectly as byproducts of coking and refining operations.
- Identify and develop a universal building block that is consistent and uniform and can be made from various carbon sources that feeds diverse uses.
- Improve basic understanding of fundamental aspects of carbon chemistry.
- Establish mechanisms to support new applications for carbon products (e.g., pool of funds managed by an industry organization modeled after the Gas Research Institute, greater support for applications engineering in universities and government, focused consortia or partnerships).
- Develop new materials and improve materials quality to respond to customer needs (e.g., longer life for anodes used in production of aluminum).

### **5.2 Improved Manufacturing Technologies**

- Develop flexible manufacturing technology.
- Improve asset utilization by 35%.
- Lower cycle time in precursor processing by 25%.

- Develop new, innovative continuous processes that yield quantum benefits for multi-stage manufacturing lines.

### **5.3 Energy and Environment**

- Establish partner relationship with the power generation industry.
- Double the use of renewable energy sources in carbon product processes and identify alternate sources of thermal energy other than fossil fuels.
- Increase energy efficiency in carbon products processes by 25%.
- Reduce emissions of hazardous, greenhouse, and other controlled gases by 80%.

### **5.4 Training and Human Resources**

- Establish training and education partnership with unions/work force.
- Industry should assume more leadership in structuring undergraduate and graduate academic curricula and courses in carbon science and processing.
- Create an environment for continuous learning (e.g., scholarships, fellowships, co-ops, internships, learning centers for reeducation).
- Promote government support of students in applied carbon science research.

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## **Appendix 1**

### ***Photo Credits***

#### **Page 3**

*Spherical carbonaceous liquid crystals growing in coal-derived pitch*

Courtesy of Dr. Peter Stansberry, West Virginia University

#### **Page 8**

*Specialty graphites*

Courtesy of UCAR Carbon Company Inc.

#### **Page 11**

*Carbon composite recreational products*

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#### **Page 14**

*Heavy vehicles, electric and hybrid vehicles, and Indy race cars all use carbon composite materials*

Upper left: “T2000” Courtesy of Kenworth Truck Co.

Upper right: “Solectria Sunrise” Courtesy of Solectria Corporation. See their website at [www.solectria.com](http://www.solectria.com)

Bottom: “Bryan Tyler, No. 17” Courtesy of Indianapolis Motor Speedway.

#### **Page 17**

*Aerospace applications of carbon composites – Stealth Bomber*

*Graphite wing molds produced by UCAR Composites Inc.*

#### **Page 18**

*Electric Arc Furnace*

#### **Page 20**

*Infrastructure restoration using carbon composite materials*

Clockwise from left:

“Before,” “After” and “Restored Concrete Tank” Courtesy of Composite Retrofit International and TYFO S Fibrwrap Systems. See their website at [www.tyfosfibrwrap.com](http://www.tyfosfibrwrap.com)

“Complete application of cap beam and column retrofit” Courtesy of XXsys Technologies, Inc. See their website at [www.xxsys.com](http://www.xxsys.com)

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